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A preliminary discussion of the relationship between population energetics and the management of southern Gulf of St. Lawrence cod.

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Introduction

Cod *(Gadus morhua L.)* have been fished in the Gulf of St. Lawrence for more than a century during the ice-free summer months. Prior to the mid-forties the fishery was primarily by baited hook or jigger, and it was not until otter trawls were first introduced by Canadian fishermen that any significant changes took place in this fishery. The introduction of foreign otter trawls in the mid-fifties had a major effect on the fishery.

This cod stock, delineated in three tagging studies has been shown to occupy only ICNAF Division 4T and Subdivision 4Vn (McCracken 1959; Martin and Kohler 1964; Kohler MS 1975). There are two main areas where the fish appear to congregate and where the fishery on them is concentrated: first, the Magdalen Shallows between the Magdalen Islands and the Gaspé-Bay Chaleur; and second, the edge of the Laurentian Channel off the northeast coast of Cape Breton. The annual migratory pattern is from the Magdalen Shallows in the fall to the area of dense winter concentration in the so-called Sydney Bight. In May, following "break-up", they again migrate to spawn in the highly productive shallows of the southern Gulf (Palohiemo and Kohler 1968). This stock supports two fisheries, the summer fishery in the southern Gulf of St. Lawrence and the winter fishery off Cape Breton. Traditionally, increases in fishing effort have been associated with increased foreign interest in the winter fishery.

Between 1936 and 1953 the average catch from this fishery was approximately 33,000 M.T., a figure which fishermen at the time thought was optimal for a sustained fishery. The fishery would probably have continued at this level if it had not been for the onset of the epzootic disease (Sinderman 1958).

The epizootic disease had catastrophic effects on the Gulf of St. Lawrence ecosystem by virtually decimating the entire pelagic fish community. From a scientific point of view it was rather opportune since this violent perturbation allowed for a wide fluctuation in the stock-dependent variables controlling the cod production system. Thus, as in good experimental design variations in the independent variables became great enough that significant changes in the dependent variables could be noted.

Furthermore, the "die-off" of the pelagic biomass facilitate the growth of cod Kohler (1964), improved recruitment (Lett and Doubleday 1976) and generally led to an increase in the exploitable cod biomass. During the period between 1954 and 1957 there were four year-classes of aged 3 fish in excess of 10^8. These sort of changes have also been noted in the North Sea where the increase in cod biomass is attributable to the decline in the pelagic biomass (Jones MS 1976).

In the late fifties the pelagic biomass in the Gulf of St. Lawrence began to recover with two large, 1958-59, herring *(Clupea harengus harengus)* year-classes being produced in conjunction with the 1959 year-class of mackerel. As the pelagic biomass increased the 3+ cod biomass declined rapidly from a high of 560,000 M.T. in 1955 to a low of 156,000 M.T. by 1967; in part due to a substantial increase in fishing effort. During this period the average catch of the Southern Gulf stock was 78,000 M.T. with the peak catch in 1956 being 110,000 M.T.

However, a preliminary analysis of the data would show that the management of this stock is only partially reliant on the manipulation of fishing effort. Indeed, the calculation of fishing mortality between 1960 and 1975 indicates that the exploitation rate is much lower than has been experienced by other cod stocks fished in a sustainable manner. Thus the present critically low level of stock biomass is probably more the result of interactions with other fish stocks than the effects of so-called single-species-model exploitation.

This paper attempts to interpret the effects of multispecies interaction in the light of the internal dynamics of the cod stock as it relates to its management. Two previous papers (Lett et. al. 1975 and Lett and Doubleday 1976) have set the framework for this further attempt. It is anticipated that some earlier confusion related to the bioenergetics can be clarified and the very important relationships between population energetics and stock management will be elucidated.

The Basic Data for Assessment

Catch-at-age data

A detailed discussion of the basic data between 1960 and 1970 has previously been presented by Halliday (1972), however it is probably worthwhile to present a brief summary. Six categories of landings are considered: otter trawl landings in the periods January-April, May-August, and September-December, seine, line, and gillnet landings. Biological sampling for length and age composition of landings in these categories in

the 1960-76 period are good only from the Magdalen Shallows "summer trawl fishery". It was considered more appropriate to treat the winter Sydney Bight fishery separately despite poor sampling by all countries. Coverage of this fishery since 1970 has vastly improved especially since the fishery is now largely Canadian. Danish and Scottish seine landings were treated separately when samples were available and combined with otter trawl landings when there were no seine samples. While seine landings differed slightly from trawl caught fish, being smaller and younger they formed such a small part of the total that the error introduced by combining seine with trawl landings is small. However, gillnet and line landings could not be combined with trawl landings since the selection pattern in this fishery differs markedly from that for otter trawls. When there were no length frequency samples from line or gillnet landings in a particular year, those of the preceeding and subsequent years were combined and some 1971 samples were applied in this way to the immediately preceeding years. However since 1970 the sampling of all fisheries has been thorough and no interpolating from other years was necessary.

Catch-at-age data between 1950 and 1960 should be treated with some caution since sampling information is only available for the winter trawl fishery for the entire period (Palohiemo and Kohler 1968). Long and handlines and some gillnets made up a substantial proportion of the fishery during this period in addition to an inshore otter trawl fleet of small vessels. In years when samples were available for these gear types they were weighted into the overall catch-at-age frequency accordingly, but in years when samples were lacking an average catch-at-age frequency for that gear type was used. A substantial amount of discarding, from 1950 until the mesh regulations were strictly enforced in 1957, was practised especially of 3- and 4-year old fish. No detailed sampling of the discard is available to weight up the samples, but calculations show that the average estimation of year-class size during this period could not be underestimated by more than 10%. Catch-at-age data for the period from 1950 to 1976 is presented in Table 1.

Effort Data

The previous discussion indicates that the Gulf of St. Lawrence cod fishery is indeed diverse and between the period 1950-1976 the gear types, fishing power and gear efficiency changed dramatically. The only gear type for which effort data is consistently available is the 26-50 ton otter trawl fishery. Therefore this gear type has been used as the standard for the period. One aspect that detracts from

from its usefulness, upon first inspection, is that only ~7% of total catch is made by it as compared with 15% in early 50's. However, the correlation between the catch per unit effort (C.U.E.) of 26-50 ton vessels and 51-100 ton vessels from 1962 to the present is very good suggesting that the catch rate in this fishery still reflects the catch rates in the overall fishery.

Changes in efficiency

The efficiency and fishing power of the Gulf of St. Lawrence fleet most certainly has changed since the otter trawl fishery first began in 1947. The progressive build up of larger trawlers and the decline in prominence of the gillnet and longline fishery are only a few of these changes. To analyse for an alteration in gear efficiency a trend was sought between fishing mortality per unit effort (F.U.E.) and time. The fishing mortality values were those generated by virtual population analysis. It was noted that F.U.E. increased exponentially with time suggesting that efficiency was increasing at a constant rate. A relationship of this sort had previously been hypothesized (Halliday and Doubleday 1976) for Scotian Shelf stocks in general. Their conclusion was arrived at by an indirect method, resulting from an iterative fitting of general production models.

The relationship hypothesis for analysis was

$$(1)\quad F.U.E. = \beta_o \, EXP\,[\beta_1 \Delta t]$$

The reduction in the total sums of squares after fitting the mean due to exponential of Δt was 39% while β_1 was equal to 0.0313. This would suggest then that effort for this fishery was increasing at a rate of 3.13% per year since at least after 1957 when the proper mesh selections were enforced. Effort values were then adjusted by multiplying them by EXP [0.0313 Δt] where 1950 was considered year zero.

YEAR	EFFORT/TRIPS	CATCH/M.T.	C.U.E.
1950	3289	44023	13.38
1951	2771	34827	12.57
1952	3516	41956	11.93
1953	6572	58911	8.96
1954	6879	63901	9.29
1955	7592	65227	8.59
1956	10004	104469	10.44
1957	8917	89131	10.00
1958	10804	86582	8.01
1959	7706	70720	9.18
1960	12846	66013	5.14
1961	9144	65583	7.17
1962	8585	66664	7.77
1963	9846	70202	7.13
1964	9638	60547	6.28
1965	10786	63027	5.84
1966	15039	54851	3.65
1967	9562	41314	4.32
1968	7146	46551	6.51
1969	6438	47512	7.38
1970	8874	64459	7.26
1971	11305	56375	4.99
1972	13598	67733	4.98
1973	13446	50635	3.77
1974	19340	48746	2.52
1975	13741	39085	2.84

Gear selection

Because of the diverse nature of this fishery and its affinity for constant change a valid sequential population analysis could not be preformed until something was known about selection, so that proper starting fishing mortality (F) values can be determined. Virtual population estimates will always vary in the proper direction when incorrect starting values are used, however these values cannot be considered correct until the selection is known. Since 1957 the 4 1/2" otter trawl mesh standard has been strictly enforced although the author is not naive enough to believe the violations of this standard would not lead to some biases within the data. The only selection experiments were carried out on otter trawl selection. The selection ogive was the cumulative distribution function of a normally distributed random variate (Fig. 1) with mean 40 cm and standard deviation 7.5 cm derived from the data in Holden [ed.] (1971).

$$(2) \qquad \vartheta_a = \frac{1}{7.5\sqrt{2\pi o}} \quad EXP\ (-[(X-40) \times 7.5])^2 dx$$

In the case of long and handline selection and gillnet selection it was necessary to turn to the commercial catch sampling data. The strong 1959 year-class was chosen to follow through between ages 4 and 14 so the year-class effects would not confound the analysis. The fraction of the total catch attributable to each 30 cm length class was accumulated over the years between 1960 and 1974 as the year-class grew in length and passed through the fishery. These accumulated fractions gave a selection curve but were confounded with the effects of the abundance at given lengths.

For this reason a relationship was found between the cohort numbers at age and the average length of the cohort as it grew older. A predictive equation was developed and abundance levels for each 3 cm length grouping were estimated. By dividing these estimates into the accumulated percentages a more unbiased estimate of selection could be determined assumingly with the effects of varying abundance removed. Polynomials were fit to these relationships of the form

$$(3) \quad \vartheta_a = \beta_o EXP\ [\beta_1 L_a - \beta_2 L_a^2]$$

and the maximum of the curve was given as selection of one (Figs. 2 and 3). Selection in the otter trawl fishery begins at approximately 22 cm while in the longline fishery selection begins at 37 cm and 49 cm for the gillnets. Full selection in the otter trawl fishery occurs at 61 cm, 73 in in the long and handline and 86 cm in the gillnet. Danish seine selection is assumed to be the same as otter trawl selection.

It is rather peculiar that the selection in the long and handline fishery falls away so symetrically, however this response has been noted for other line fisheries. It would seem that the cod no longer prefer the bait in addition to the fact that the hook size may become inefficient. It is doubtful that they are not merely available to the gear since the division between size groups of fish seems to be more related to maturity. Furthermore, research surveys indicate that cod over 73 cm are available in areas of longline fishing.

These three selection curves were combined such that an overall selection for each year since 1960 could be determined for the fishery. Weighting factors were calculated for each age group and combined based on the overall catch in numbers of that age group within the gear type; the mean length of the age group dictating the selection. The results of these calculations are shown in Table 2.

Sequential population analysis

Cohort analysis (Pope 1972) was utilized to determine the numbers at age. Starting values were determined using an iterative process. First a guess was made for starting F values in 1975 and this was distributed over age according to the selection factors in that year. The starting F for the terminal ages in the different years was 0.2. Natural mortality (M) was held constant at 0.2 for all age groups. A preliminary study using Palohiemo's method indicated this to be correct for ages 3 to 14 when the C.U.E. was divided by the selection factors. However, this is not to say natural mortality does not vary with age, it is merely an average value when the geometric mean regression is used for bivariate normal data (Ricker 1973).

Estimates from cohort analysis improve as F values accumulate, thus after the initial run the average F was determined for fully recruit age class and F values for terminal years were determined by multiplying these average F's by the appropriate selection factor. The F value in 1975 was determined from a plot of fishing mortality vs effective effort. The analyais was again run, and the same procedure was followed with the exception being that the total average F for ages 3 to 15 was now correlated with effective effort until the deviation of 1974 plus 1975 from the G.M. regression line was minimized (Fig. 4). Since no selection factors were available prior to 1960 an average value of 0.28 was used in the terminal years.

The correlation between F_{3-16} and effective effort is quite good and does indicate that management of fishing effort can have substantial impact on the resultant mortality rates within the cod stock. The lack of trends in the residual would indicate errors are occurring randomly and there are no between year effects in natural mortality although nothing can be said for this relationship about age effects. The correlation of effort x selection against F does show a trend in the residual and this may be attributed to age specific natural mortality. Numbers at age and F values are shown in tables 3 and 4.

Although the plot in figure 4 does support the validity of the cohort analysis, a further check can be determined by examining the relationship between the C.U.E. and the biomass determined by multiplying the weights at age by the numbers at age.

This relationship (Fig. 5) indicates that these estimates are certainly in line with estimates of C.U.E. from the commercial fishery. In addition to linearity the line passes through the origin suggesting the numbers at age in the more recent years is neither over no underestimated. This relationship therefore supports the selection of starting F values. The F value in 1973 is rather insensitive to the starting values and in both cases, Fig.'s 4 and 5, this value falls on the line. It would appear also that effective effort in 1974 has been badly overestimates but only slightly underestimated in 1975.

Since no effort data is available for 1976 the values are merely a projection based on the numbers at age in 1975 and the catch at age in 1976. However the F values in 1976 would indicate that the selection pattern has again changed such that younger age groups are being more heavily selected. This falls in very nicely with patterns exhibited by this fishery, since in 1976 a large proportion of the catch, ~42%, came from the winter fishery where vessels tend to concentrate on the higher densities of younger fish (Table 5)

Juvenile surveys and the prediction of year-class size

Previously a correlation was found by Hare and Kohler (1975) between the logarithm of the C.U.E. of juveniles and year-class size as estimated from virtual population analysis. Further analysis of this data indicates that the transformation is unwarranted. Since the juvenile surveys in former years did not cover the entire Gulf of St. Lawrence, and were conducted with a different mesh size, the two types of surveys needed to be intercalibrated. A correlation of 0.991 was found between the C.U.E.'s of the old and new surveys between 1970 and 1972. The values from the old surveys could now be corrected in relation to the surveys since 1970.

Year-class	C.U.E. Age 2	V.P.A. Estimate Age 3
1957	4.76	134847
1958	1.21	46119
1959	1.23	60134
1960	1.27	41739
1961	1.57	61261
1962	1.26	52501
1963	1.50	61459
1964	4.64	107042
1965	2.10	95111
1966	2.26	56944
1967	0.85	50480
1968	2.54	74245
1969	0.52	23460
1970	1.19	26712
1971	2.15	39388

The correlation between the juvenile surveys and year-class size at age 3 was 0.87 (Fig. 6) however, the line does not pass through the origin. This indicates the surveys are inefficient to some degree and catch very few fish when year-class sizes are small. A geometric equation was fit to the data

$$(4)\quad N_3 = 24081.79\ C.U.E._2 + 15618.15$$

so that the bivariate normal nature of the variance is taken into account. The decision as to which regression is most appropriate is quite critical to the estimation of small or large year-classes. It may be argued that VPA estimates of year-class size are measured without error and the regression of Y on X is more appropriate. This regression would lead to smaller year-class prediction when the C.U.E. is less than approximately 2.0 and large year-classes when the C.U.E. is greater than 2.0. It is a point worthy of discussion!

Fortunately the year-classes of interest are near the mean value and would be influenced slightly by the regression. Ricker (1973) points out that the confidence limit around the G.M. regression is the same as that for univariate regression. Therefore, the standard deviation in the prediction of year-class size can be estimated by:

$$(5)\quad S.D. = t_p \cdot Sxy \cdot \sqrt{1 + \frac{1}{n} + \frac{x^2}{\Sigma x^2}}$$

where Sxy is the error mean square, n is the number of points, t_p is the student t value at the accepted level of confidence and sigma x^2 is the sum of squares for year-class size corrected for the mean.

Year-class	$C.U.E._2$	N_3	± 95%	± 70%
1972	1.46	50777	37092	18528
1973	2.55	77027	40759	20360
1974	1.94	62337	38562	19263

Thus year-class size seems to be improving (table 2), however these estimates should be viewed with caution due to the large associated variance. Other sources of information do not support these estimates and will be discussed later.

The basic data for the assessment presented here is now complete, but very little of the actual biology of these relationships has been discussed. Before further analysis is performed, a detailed biological analysis will be presented, and a simulation built for further prediction.

The Biological Background to the Assessment

Density Dependent Growth

The instantaneous growth rate of cod ages 2-15 was defined as $G = \frac{dw}{dtw}$ and calculated from weight at age data from commercial catch sampling between 1950 and 1975 (Table 5). These samples were all taken between January and April when the cod are not growing. The instantaneous growth rate can be calculated by the natural logarithm of the ratio of weights in successive years (Ricker 1958).

Lett and Doubleday (1976) have previously shown that the growth rate of cod between ages 5 and 8 in the Gulf of St. Lawrence is inversely related to the biomass, and that the biomass indeed reflects the density since no changes in catchability have been noted during the period. However, since this is an average rate it is difficult to apply it to the overall stock. According to Kerr (1974) the instantaneous growth fishes should be an inverse power function of their weight. In theory this is fine, however one wonders to what degree the fit of such a relationship is due to the auto correlation of the independent and dependent variables. Laboratory experiments have shown that the basal metabolic rate of fish drops with size (Beamish et. al. 1975) suggesting that this relationship is indeed correct; thus it would seem appropriate to linearize the data using a double logarithmic transformation for hypothesis testing.

Another variable, which does not vary in a continuous manner overtime, are the accumulation of events which occurred during the epizootic disease in the Gulf of St. Lawrence (Sinderman 1958). During the period from 1945 to 1958 the biomasses of mackerel and herring were almost totally decimated. The disease which started gradually and caused catastrophic mortalities near its termination may be related to higher than average water temperature which prevailed during this time. The growth rate of cod was increased since they were eating diseased herring which could easily be captured. Furthermore, more energy was possibly being transferred directly into the benthos without first being assimilated by the pelagic community.

This would increase the carrying capacity of the benthos, and the number of available food items for young and old cod alike. This situation in the Gulf of St. Lawrence is similar to that noted in the North Sea where the pelagic biomass is now at a very low level because of over-exploitation, but substantial increases have been noted in the cod biomass. Jones (MS 1976) has presented a preliminary investigation of possible energy flows in the North Sea system which elucidate the partitioning of energy such that the measured changes could occur.

Palohiemo and Dickie (1966) suggest the metabolic exponent is constant while the proportionality constant varies to environmental condition. Farmer et. al. (1977) found this was not true for the growth of sea lamprey since both the exponent and proportionality constants were acted on by environmental variables. For this reason the following form of equation is put forward to describe the growth of cod:

$$(6) \quad \frac{dw}{dtw} = \beta_o \cdot B^{-\gamma_1} \cdot W^{-\gamma_2} \cdot B$$

where B is the biomass of cod before the summer fishery begins and W is the weight of cod in kg.

Multiple regression was used to determine parameter values and a dummy variable D represents the collective effects of the epizootic disease on growth. The dummy variable is zero when there is no epizootic and one when it is occuring. The following intrinsically linear model adequately describes the instantaneous growth rate of cod:

$$(7) \quad \log_e G = -0.0517 \log_e B \times \log_e W - 0.2515 \log_e B + 0.1472 \log_e W \times D + 1.88691$$

Variable	Coeff.	S.E.
$\log_e B$	-0.2515	0.0922
$\log_e B \times \log_e W$	-0.0517	0.0050
$\log_e W \times D$	0.1471	0.0803

The coefficient of multiple determination (R^2) is 0.47 while F (significant at $P < 0.05$) for regression is 65.32 ($F^{1}_{3,221} / 2.60$).

The significant interaction between weight and the dummy variable indicates that when the epizootic is not occurring weight is more influential on growth rate. This would suggest that the epizootic infact increased the energy intake of cod which seems to be the case. Since the epizootic is not a "normal" event in the management of cod the most useful equation would be:

$$(8) \quad G = 6.6000B^{-0.2515} \times W^{-0.0517 \log_e B}$$

As the weight of cod increases the growth rate declines rapidly (Fig. 6) with the growth rates of smaller fish being more effected by shifts in biomass than older fish. This would make density dependent growth in most fish stocks extremely hard to detect.

Density dependent Z_1 growth

The occurrence of density-dependent growth during the first year of life in the Gulf of St. Lawrence cod stock was investigated using the back-calculation of 2500 otoliths taken from commercial sample surveys for the years 1960-1975. For each year, 150 otoliths covering all available age groups were read according to the established methods of Kohler (1964) and May (1967). The left otolith from each fish was broken across the sulcus, both halves were smoothed with emery paper when necessary, placed into a plasticene substrate, covered with alcohol and examined at 25 x magnification under a binocular microscope. The interface between the outside edge of the opaque band and the inside edge of the hyaline zone was taken to be an annulus. The distances between the focus and each respective annulus were measured with the aid of an ocular micrometer in a radius perpendicular to the otoliths' longitudinal axis. These distances were tabulated with the fishes' length; values for crystallized or unreadable otoliths were not used. The regression between fish length (L) and otolith radius (R_o) was $L = 0.628\ R_o^{1.227}$ with an R^2 of 0.73. According to age and year of capture, the otolith measurements for each fish were sorted into year-classes. The sample sizes ranged from 32 for the 1950

year-class to 183 for 1964 and 27 for 1972. The mean length in centimeters for each year of growth of all year-classes was tabulated.

Density-dependent l_1 growth has been shown to exist for clupeids (Marr 1960, Iles 1968, Lett and Kohler 1976) and for gadoids (Raitt 1939, Doubleday et. al. 1976). The formation of the first annulus has been argued by Lett and Kohler (1976) as being a response to carrying capacity, environmental heterogeneity and predatory pressure. This predation is not a direct but secondary one, leading to the consumption of larvae and juveniles which are weakened by starvation (Jones 1973). Both temperature and a holistic variable representing the change in the carrying capacity as a result of the epizootic disease should therefore significantly alter the formation of l_1 length. The hypothesis was the l_1 length was a power function of year-class size and the exponent could be altered by the logarithm of temperature. Again a dummy variable was used to represent the epizootic, 1 when it was occurring and zero when not. The following equation described much of the variation in l_1 length:

$$(9)\quad \log_e l_1 = 0.2999 \log_e N_3 + 0.27251 \log_e N_3 \times D - 2.9395 \times D + 0.02201 \log_e N_3 \times \log_e Tp + 4.71572$$

Variable	Coeff.	S.E.
$\log_e N_3$	-0.2999	0.0459
$\log_e N_3 \times D$	0.2725	0.0931
D	-2.9395	1.0486
$\log_e N_3 \times Tp$	0.02202	0.0132

The coefficient of multiple determination (R^2) was 0.71 while F (significant at $P<0.05$) for regression is 10.79 ($F'_{4,18}/2.29$).

N_3 is the numbers in a particular year-class x 10^{-3} at age 3, while l_1 is the length of the fish at the time of formation of the first annulus and Tp is the spring temperature at Grande Riviere on May 25.

As year-class size increases, there is an exponential decline in l_1 length (Fig. 7). (The figure has been corrected to 6°C and represents lengths when the epizootic is not on.) The shape of this relationship agrees well with the exponential decline in l_1 length for silver hake in response to year-class size noted by Doubleday et al. (1976).

A more useful form of the equation when the epizootic is not occurring is:

$$(10) \quad l_1 = 5.907\ N_3^{[0.5724 + 0.0222 \times \log_e Tp]}$$

The yearly fluctuations in the first year of growth are most interesting. The variations could not be explained by either Lee's phenomenon or an increase in experimental error, in fact statistical confidence was highest for the first year growth measurements. The relationship between this crucial growth period and the ensuing recruiting stock size seemed to satisfactorily account for much of the variation. Concommitant with density dependent first year growth is a suggestion of growth compensation in the second and third years; where first year growth was low, second year growth was usually high, with the converse always being true.

The phenomenon of density dependent growth has been viewed as obvious by some and dubious by others Cushing (MS 1976), but is certainly suggested by this study. This is probably because changes in the rate of accumulation of surplus energy are more manifested in fluctuations in gonadal rather than somatic weight in mature fish, making changes in body weight much harder to detect as fish get older.

Shifts in maturity with length

Maturidy of some time has been considered a fixed function of length. However, the recent works of Daan (1974) and DeVeen (1976) indicate that this biological trait is dynamic for cod and plaice. Shifts in the maturity ogive have also been noted

for Gulf of St. Lawrence cod (Fig. 9) with the mean length of maturity dropping 13 cm since 1959. Small shifts in maturity can have an extreme impact on the total egg production of the population this it would seem that a trait as powerful as this one should have some biological significance. In addition, it is not intuitively obvious why maturity should shift with length.

It has been noted by Beverton (1959) that maturity usually occurs at the inflection of the relationship og growth over time. That is to say, when the rate at which fish are gaining weight over time begins to decline the fish reaches maturity. Therefore it would seem that the length at which maximal growth rate is achieved determines the onset of maturity.

It has been noted in mammalian populations that growth determines the age of maturity in addition to the size. Personal observation has shown that, rainbow trout fed a maximum diet will mature in the first year of life at a length far less than wild fish. For this reason, it was hypothesized that the growth rate of cod during the first year probably strongly influences the length at which they mature. Indeed, this does seem to be the relationship (Fig. 10). A mechanism such as this has strong homeostatic value in relation to maintaining population stability. A strong year-class grows more slowly in the first year of life and matures at a larger size. Thus the effect of this good year-class on the reproductive biomass does not as quickly as a small year-class. However, if a stock is collapsing and year-class size is beginning to diminish then these fish will mature much sooner than if the ogive were fixed, augmenting the size of the reproductive biomass quite dramatically. The effect of this relationship on the population stability and subsequent stock management will be discussed later.

Cod Adult Stock Production and Egg Production

The mechanism by which the egg production of a fish stock is related to the production of the adult stock has been discussed by Lett (MS 1976), Lett and Kohler (1976), Lett et al. (1975) and Tyler and Dunn (1976). Recently DeVeen (1976) has presented data showing a continual increase of fecundity at length for sole either because of a decrease in stock or an increase in food or both. Bagenal (1973) has also not the same types of changes for North Sea plaice.

The hypothesis being put forward in this paper is that fecundity is related to the food intake and the partioning

of the proportion of surplus energy into gonad is reliant on the total available surplus energy. Mathematically this paradigm can be represented mathematically by the equation:

$$(11) \quad E = N \times (\Delta W)^{\gamma}$$

where E is the egg catch in the Gulf of St. Lawrence surveys per 100,000 m^{-3} of water, N is the number of mature fish and ΔW is the weighted growth rate of the mature stock. The exponent, γ, is the rate at which surplus energy is being channeled to gonad in relation to the overall surplus energy represented by a change in weight.

Lett et al. (1976) have shown that temperature (Tp) influences the survival of eggs and influences the catches on the egg and larval cruises. In addition, it has been shown that temperature acts in a quadratic manner which agrees with the findings of Forrester and Alderdice (1966) and Bonnet (1939). There the following equation was fit using multiple regression to represent the catch of eggs during the time of peak spawning.

$$(12) \quad \log_e E/N = \beta_1 \log_e \Delta W + \beta_2 Tp + \beta_3 T^2 + \beta_o$$

Parameter	Value	St. Error
β_1	1.2221	0.3640
β_2	1.6769	1.1114
β_3	-0.1655	0.1071
β_0	2.0667	

The reduction in the total sums of squares, after fitting the mean, due to regression was 77.3%, with an $F = 6.8$ ($F^{1}_{3.6}$ / 4.76). The equation can be rearranged to the following form.

$$(13) \quad E = 7.900 \times EXP\ [1.677Tp - 0.166\ Tp^2] \times N(\Delta W)^{1.222}$$

where Tp is the mean sea surface temperature occurring on

the cruise. Although neither β_2 or β_3 are significant the combined effects of the fitting of these two parameters led to an improvement to the overall fit of 9%. Most of the variation in egg catch per mature individual is explainable by the growth rate, 69% or the production of surplus energy by individual fish (Fig. 11).

The existing dogma relates eggs production to the mature stock biomass and this is usually converted to eggs by the multipication of some fixed fecundity length relationship. Equation (13) shows that clearly for cod this is not the case. However, for a stock where ΔW did not change then there would be a linear relationship between biomass and egg production, but this has limited biological meaning. Twice (Lett et al. 1975), (Lett and Doubleday 1976) a dome shaped egg production curve has been presented as a function of biomass. It was hypothesised at that time that density dependent growth led to the production of this dome shaped curve. Equation (13) certainly supports this conclusion since according to equation (8) ΔW should decrease as N increases and the rate at which egg produce declines with density depends on the exponent of ΔW.

The Production of Larvae

The survival of fish larvae has been a topic of particular concern to fisheries biologists for the past century. A number of notable papers have been produced relating the survival to environmental effects (Hjort 1916, Hempel 1965, Postuma and Zijlstra 1974 and Cushing 1975) and the density dependent effects (Beverton and Holt 1957, Beverton 1962, Cushing and Harris 1973, Jones 1973, Cushing 1975) however, few papers consider the combined effects of the environment and density dependence presenting the results in a quantitative manner. Exceptions to this however are the works of Ware (1975), Lett et al. (1975) and Lett and Kohler (1976).

The model being developed in this paper incorporates the two effects and presents a quantitiative model. The normal assumption concerning the survival of fish is that:

$$(14) \quad \frac{dN}{dt} = \beta_o N$$

or that the instantaneous growth rate is constant. Cushing (1975) and Ware (1975) found this was not an adequate model for explaining both the mortality of fish larvae in addition

to older stages of fish. Cushing decided that instantaneous growth was indeed density dependent and reformulated the survivorship equation as:

$$(15) \quad \frac{dN}{dt} = \beta_o N^2$$

Ware's (1975) sophistication of the problem hypothesizes that mortality is related to the growth rate an agreement which seems well supported by the data. Unfortunately, the data is not yet available on the growth of juvenile and larval cod so in this study it is proposed that the mortality rate responds to density.

It is assumed that the structure of the relationship between density is not known. A plot of the instantaneous mortality verses numbers over the period when larvae are available is an asymptotic relationship with population density such that:

$$(16) \quad \frac{dN}{dtN} = \beta_1 \log_e N + \beta_2 [\log_e N] \times Tp + \beta_o$$

Parameter	Value	S.E.
β_1	1.639×10^{-2}	2.470×10^{-3}
β_2	1.751×10^{-5}	1.000×10^{-5}
β_o	-0.0485	

where Tp is the annual monthly maximum temperature. The reduction in the total sums of squares, after fitting the mean, due to regression is 88.7% with an F of 35.3 ($F^1_{2,9}$ / 4.26). What the equation implies is that if the number of eggs is known and the temperature, the number of surviving larvae is predictable at a later date. Of all models considered equation 16 gave the best fit. This equation must be solved iteratively since there is no closed form for intergration. Thus the equation in the following form must be solved iteratively:

$$(17)\quad dN = [1.639 \times 10^{-2} \log_e N\ (1-1.0683\ Tp) - 0.0485] \times N_o \times dt$$

$$(18)\quad N^1 = N_o + dN$$

$$(19)\quad N_o \leftarrow N^1$$

Where N_o is the initial number of animals and N^1 is the number remaining after the time step dt. The solutions of the equation are extremely stable when the dt is one day. The number of larvae are estimated after 50 days and the results are the same as previous preliminary analysis (Lett et al. 1975). The final number of larvae seems to vary less than the initial number of eggs which indicates that competition among cod larvae tends to thin the population out such that carrying capacity of the environment can be met. Temperature in turn probably is modifying the food supply such that when temperature is high and more plankton is available there is less competition, thus greater survival. This same type of density dependent relationship has been noted for mackerel larvae (Lett et al. MS 1975b) and is an important stabilizing force in the recruitment mechanism. Large variations in egg production and survival at this stage can be severely damped through this process. Harding and Talbot (1973) present a number of survivorship curves for plaice which indicates the same response, that is the number of surviving larvae is much more invariate than the number of eggs.

Factors effecting year-class size formation

Previous attempts to derive an equation describing the formation of year-classes from larval abundance have incorporated the effects of predation of older cod on juvenile cod as they become demersal (Lett and Doubleday 1976). However this equation did not adequately explain the data, especially in the description of the most recent small year-classes. The

conclusion that Lett and Doubleday (1976) came to was that an important variable was missing.

This most recent analysis indicates that the missing variable is possibly the impact of mackerel predation of cod larvae since mackerel enter the Gulf when cod are beginning to hatch in large numbers and remain in the same areas that cod larvae are found for the entire summer. It is known mackerel eat other fish larvae (MacKay 1976), and there is no reason to believe cod represent a special case. Mackerel have been shown to effect year-class formation of Gulf of St. Lawrence herring (Lett and Kohler 1976, Winters 1976) and 4W haddock (unpublished data). In fact, Lett et al. (1975) have suggested that mackerel are extremely influenced on the recruitment of any fish stock with which they co-habitat. Unfortunately, no stomach content data exists for mackerel while resident in the Gulf of St. Lawrence showing the consumption of cod larvae.

Correlation analysis showed the effect of mackerel, cod, and cod larvae and the survival of cod larvae was as follows:

Variable	N_3/LR	BMACK	BCOD	LR.
N_3/LR	1.000	-0.777	0.118	-0.755
BMACK	-	1.000	-0.496	-0.491
BCOD	-	-	1.000	-0.316
LR.	-	-	-	1.000

The following form was proposed for the larval recruitment equation:

$$(17)\quad N_3 = \beta_o . L_R . EXP[\beta_1 BMACK + \beta_2 BCOD + \beta_3 L_R]$$

where BMACK is the biomass of 1+ mackerel, BCOD is the biomass of 3+ cod when the cod juveniles are 3 year old and become demersal and L_R is the abundance of larvae on day 50 after peak spawning as predicted by equations (13) and (16-18). This equation indicates that the greatest influence of larvae on year-class formation occurs when the biomass of cod and mackerel

are amsll and since environmental variables such as temperature enter in through varying larval abundance the environmental effect should also be greatest at small stock sizes. Walters (1975) has suggested a mechanism for salmon whereby the environmental variable and stock size interact which does not seem correct for cod since the variance in year-class size diminishes with an increase in stock size.

The following auto-correlated function was used to fit the model:

$$(17)\quad \log_e \left[N_{3/LR}\right] = \beta_1 BMACK + \beta_2 BCOD + \beta_3 L_R + \beta_o^1$$

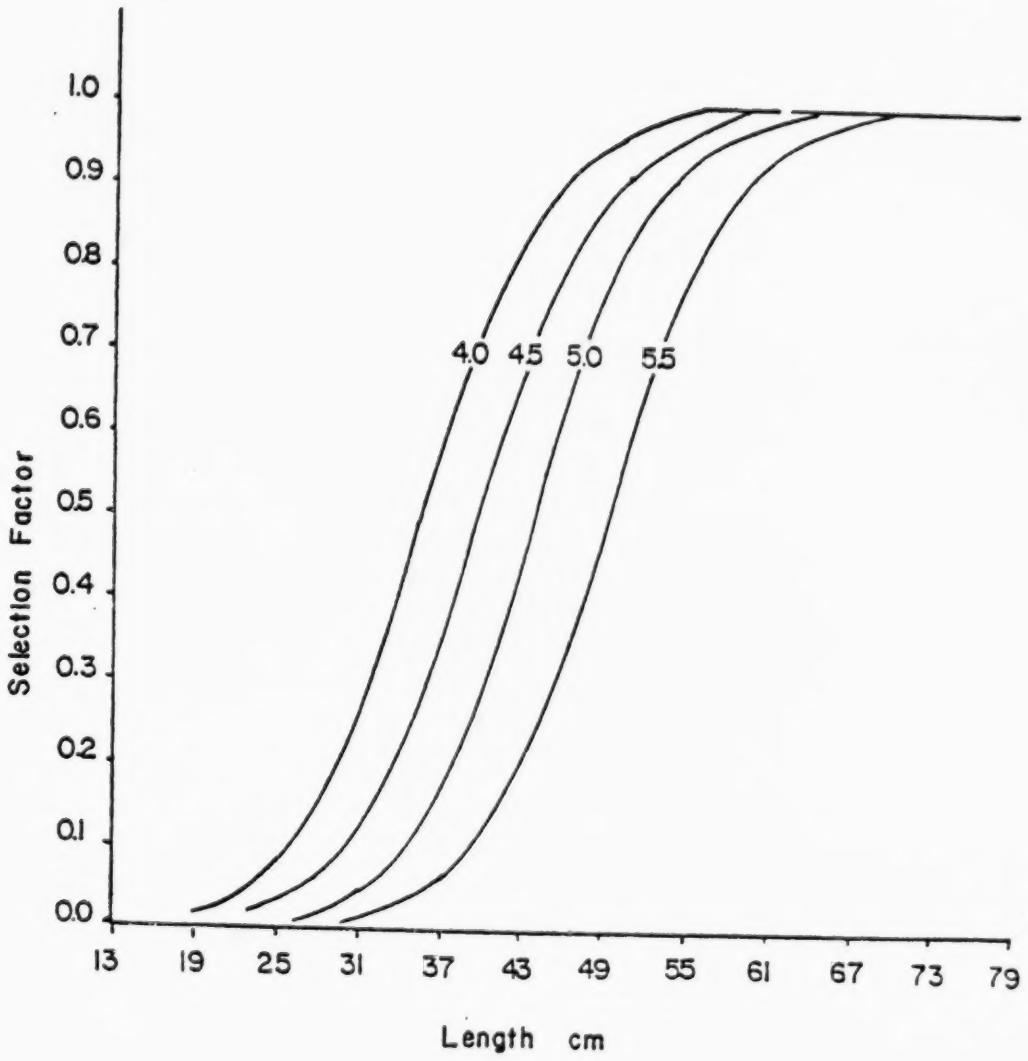
Parameter	Value	SE	Variation explained
β_1	-6.102×10^{-7}	1.110×10^{-7}	0.603
β_2	-5.751×10^{-6}	1.670×10^{-6}	0.128
β_3	-2.807×10^{-3}	6.300×10^{-4}	0.183

The reduction in the total sums of squares due to the fitting of the regression was 91.4%. The goodness of fit is not represented properly by this value, however since the relationship is auto correlated and a better representation of the actual fit is found in figure 12 where mackerel biomass is held at zero and cod at 150,000 mt. The 1968 year-class again is the only one not well explained by larval abundance and predation. Similarily, the 1968 year-class was not well explained in the year-class size t_1 relationship (Fig. 8). Possibly another variable is missing in the recruitment relationship but under most conditions year-class size is explainable.

As larval abundance increases so does year-class size then after a maximum begins to decline (Fig. 13a). What this implies is a density dependent mechanism by which weakened larvae succumb in greater numbers than the carrying capacity for these larvae would dictate. As the cannabalism of cod becomes greater, the year-class sizes are suppressed. Both mackerel and cod predation have a dramatic effect on year-class formation (Fig. 13b). However, it requires almost 10 times the biomass of mackerel eating herring larvae to have the same effect as cod eating juvenile cod.

Thus although over the data series analysed, mackerel has been the dominant character dictating year-class strength in cod, cod actually has much more influence on itself per unit biomass. It is only because mackerel biomasses have been so much greater than cod biomass that this population has lost much of its ability to regulate itself.

Fig 1


1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Selection Factor
4.0
4.5
5.0
5.5
13
19
25
31
37
43
49
55
61
67
73
79
Length cm

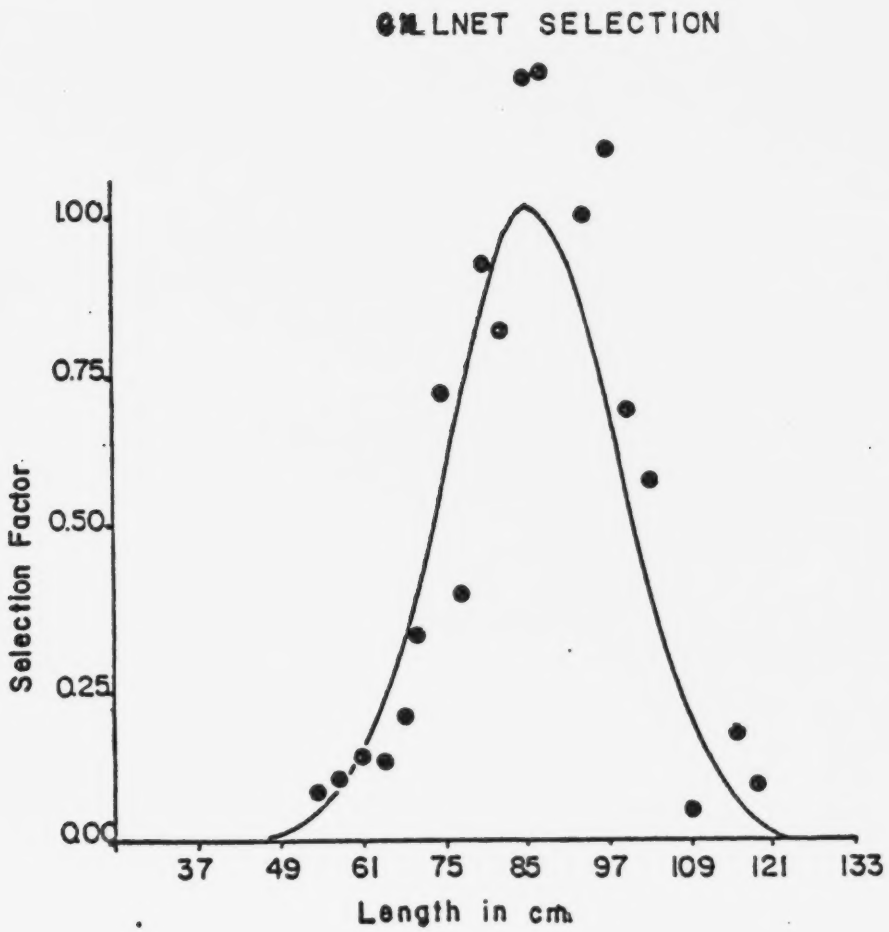

GILLNET SELECTION
1.00
0.75
0.50
0.25
0.00
Selection Factor
37
49
61
75
85
97
109
121
133
Length in cm

Fig 3

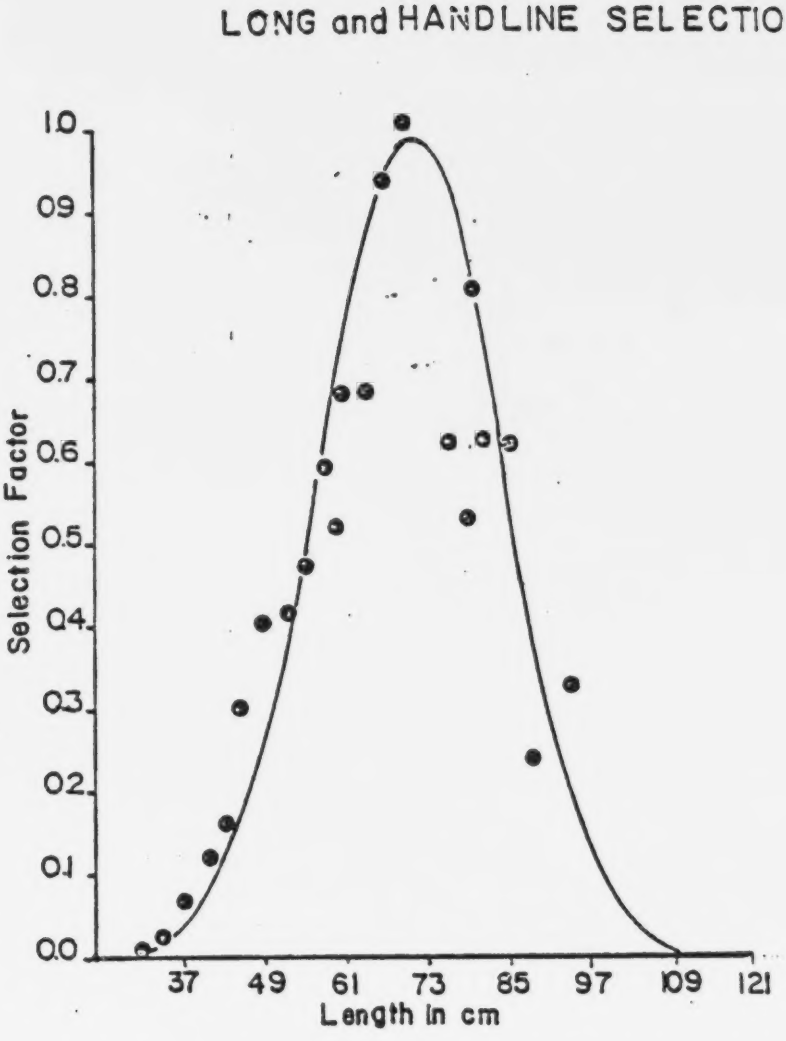

LONG and HANDLINE SELECTION
Selection Factor
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
37
49
61
73
85
97
109
121
Length in cm

Fig 4

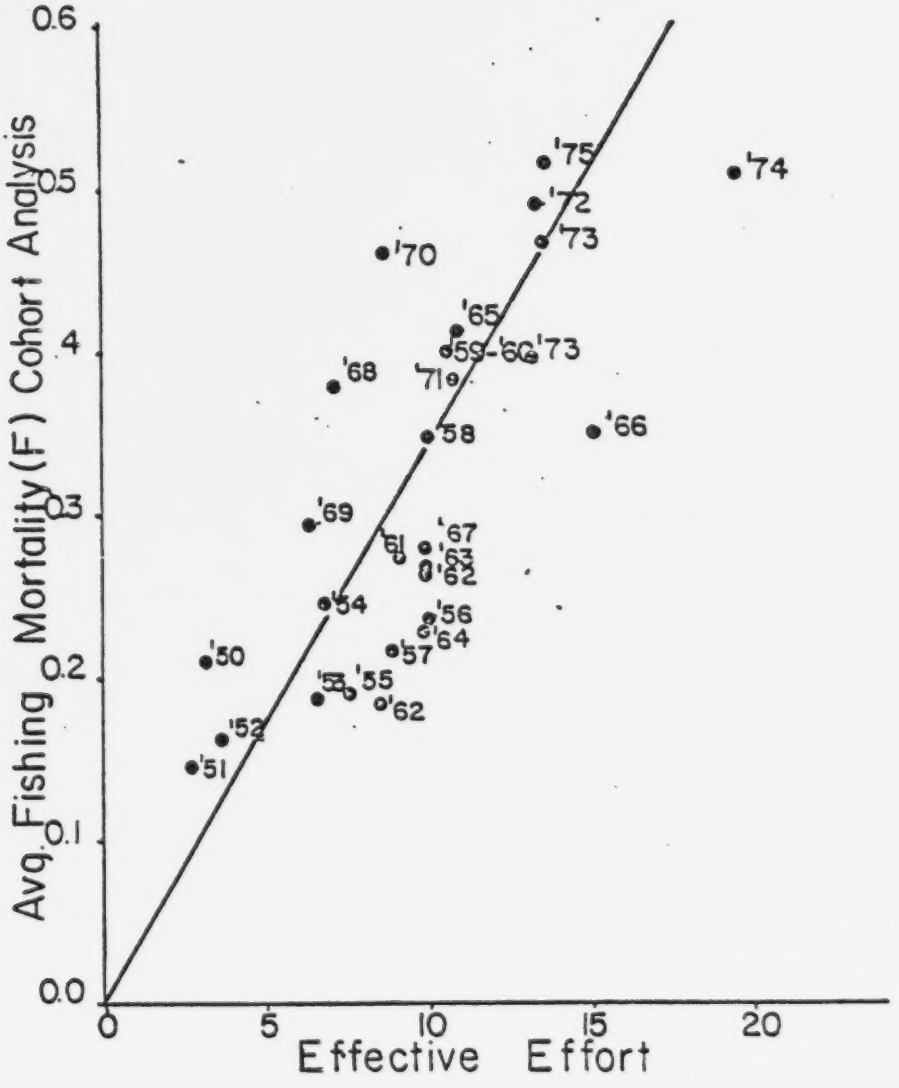

Avg. Fishing Mortality (F) Cohort Analysis
Effective Effort
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0
5
10
15
20
'50
'51
'52
'53
'54
'55
'56
'57
'58
'59
'60
'61
'62
'62
'63
'64
'65
'66
'67
'68
'69
'70
'71
'72
'73
'73
'74
'75

Fig 5

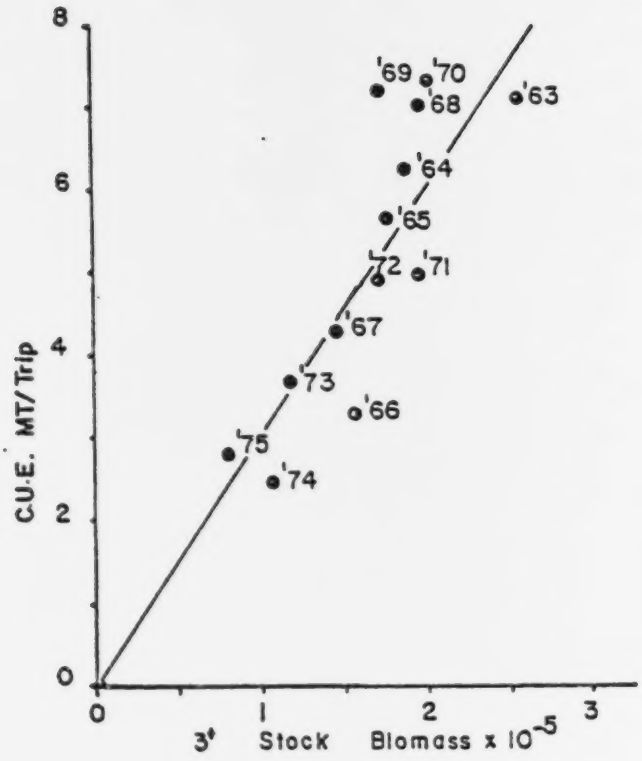
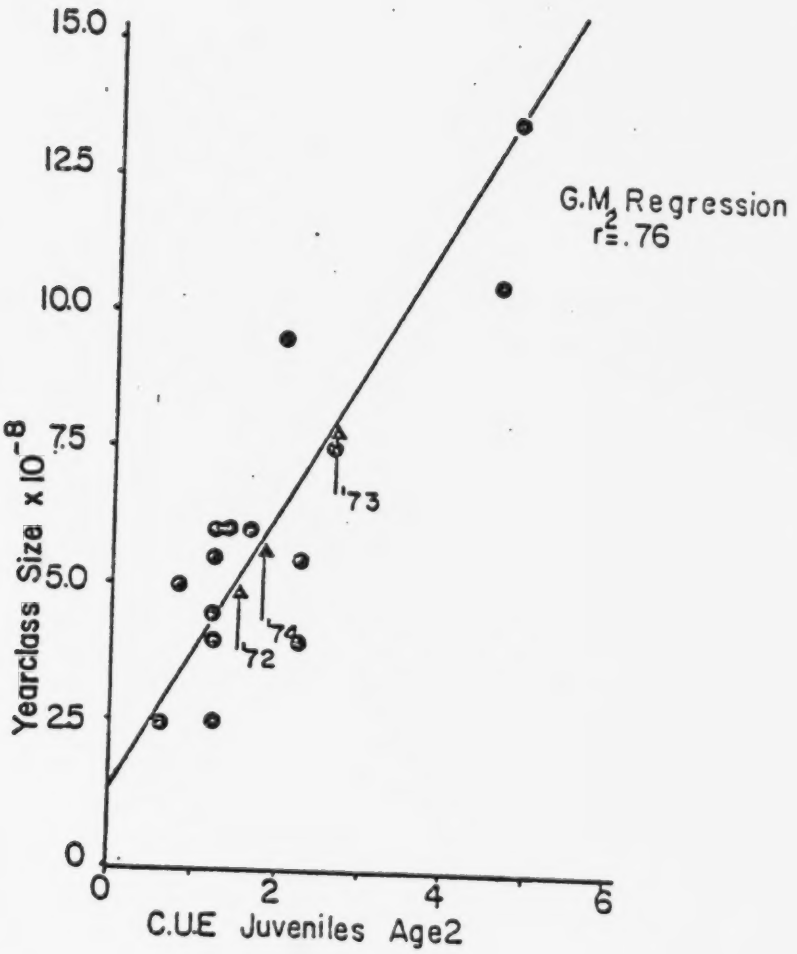

8
6
4
2
0
C.U.E. MT/Trip
'69
'70
'68
'63
'64
'65
'72
'71
'67
'73
'66
'75
'74
0
1
2
3
3' Stock Biomass x 10^-5

Fig 6


15.0
12.5
10.0
7.5
5.0
2.5
0
Yearclass Size x 10^{-8}
0
2
4
6
C.U.E Juveniles Age2
G.M. Regression
r^2=.76
'73
'72
'74

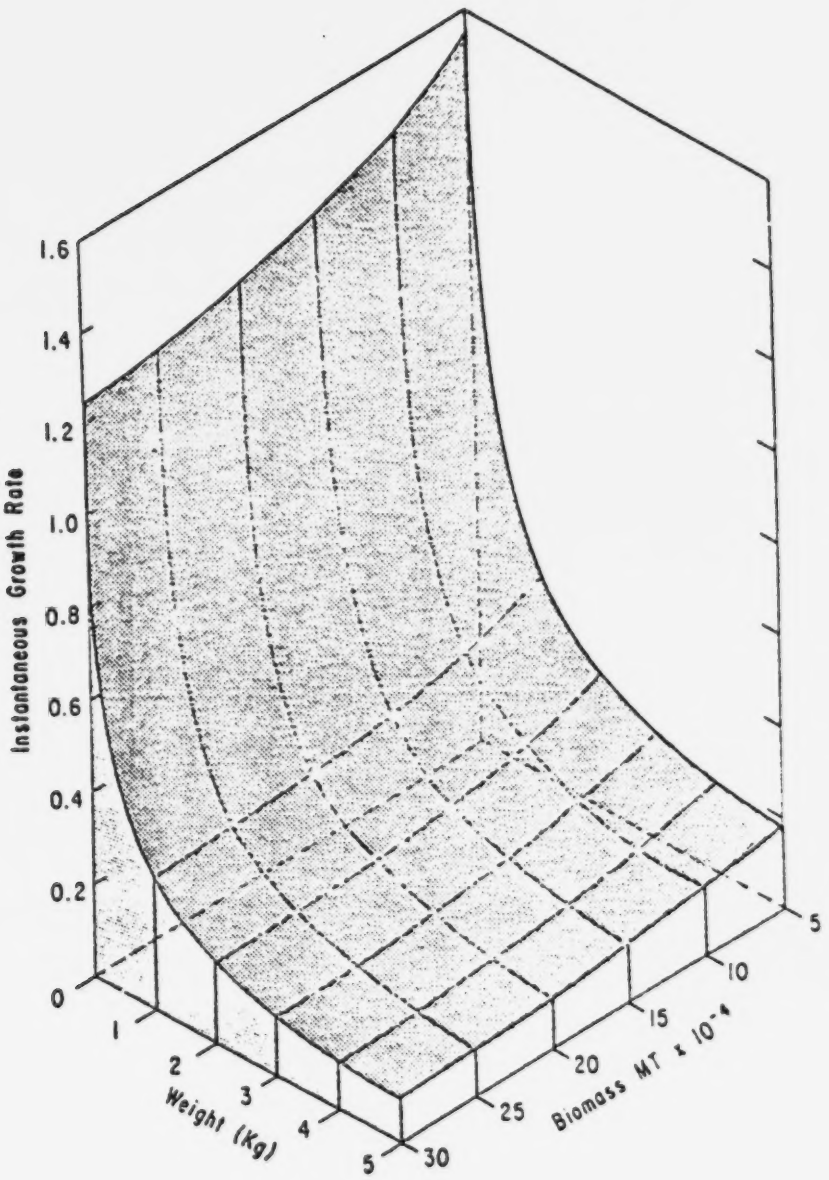

Instantaneous Growth Rate
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
1
2
3
4
5
Weight (Kg)
30
25
20
15
10
5
Biomass MT x 10⁻⁴

Fig 8.

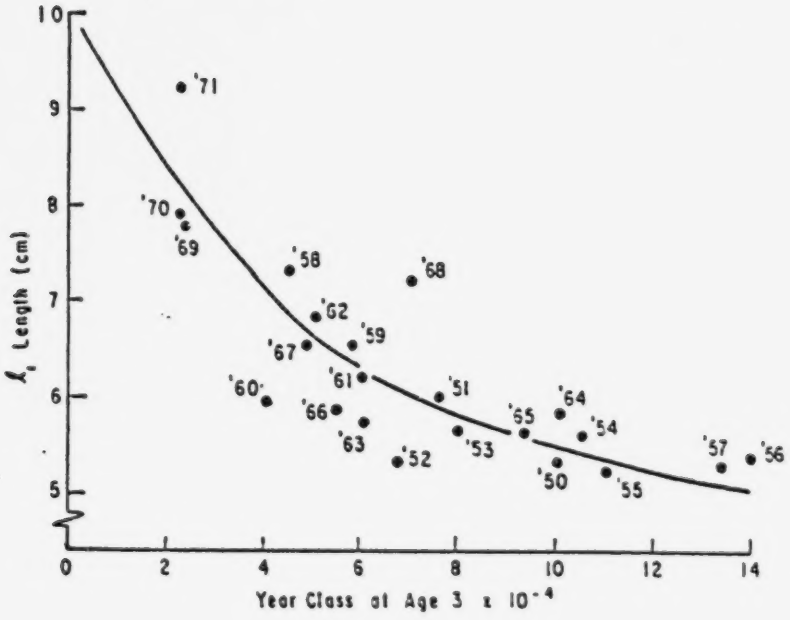
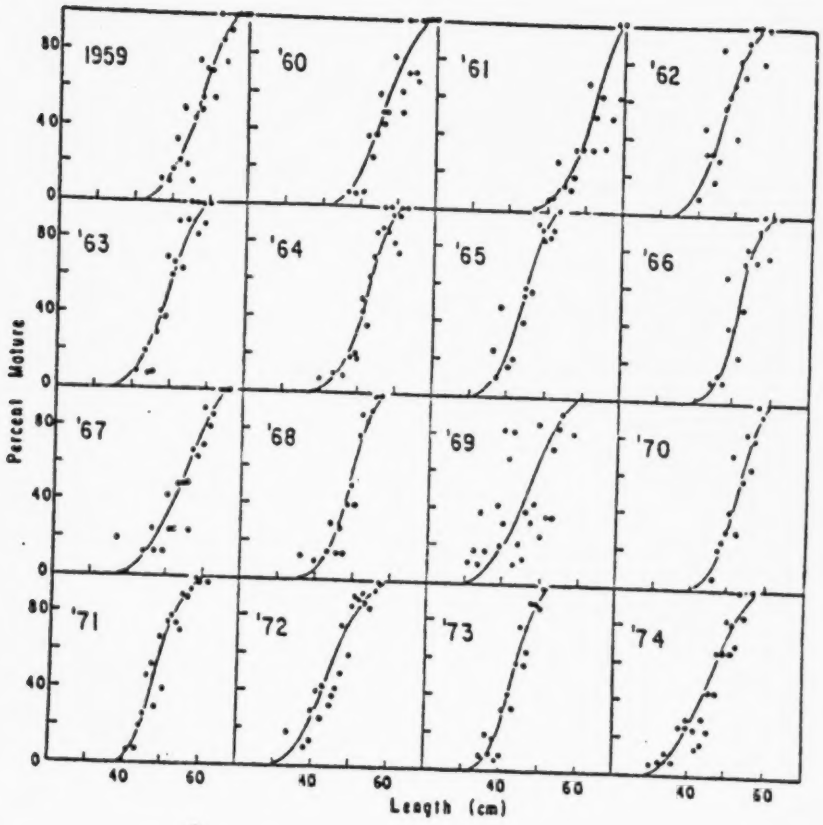
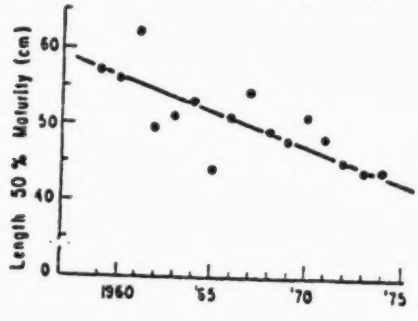
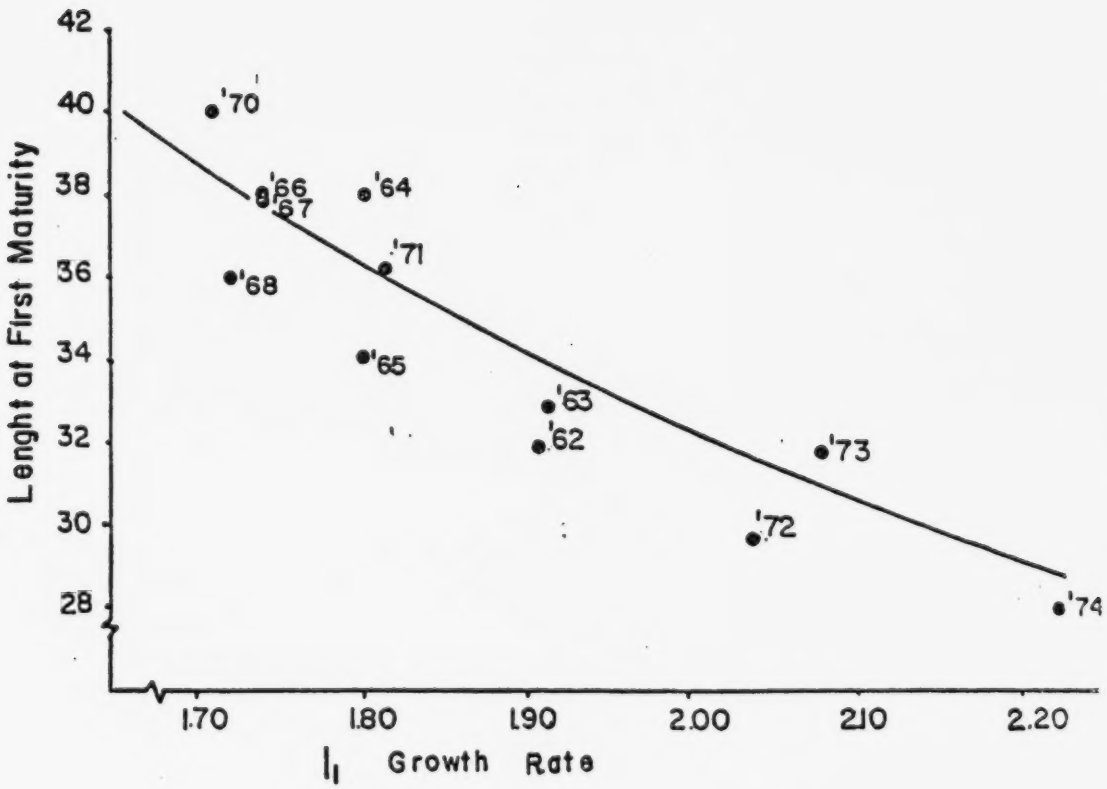
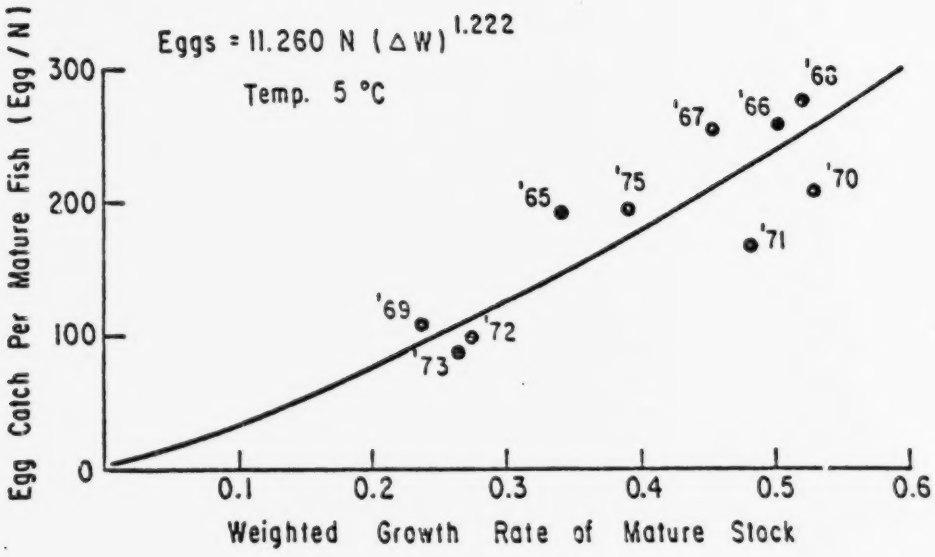

10
9
8
7
6
5
ℓ_∞ Length (cm)
'71
'70
'69
'58
'68
'62
'59
'67
'61
'60
'51
'66
'64
'65
'54
'63
'53
'52
'57
'56
'50
'55
0
2
4
6
8
10
12
14
Year Class at Age 3 x 10^{-4}

Fig 9


1959
'60
'61
'62
'63
'64
'65
'66
'67
'68
'69
'70
'71
'72
'73
'74
Percent Mature
Length (cm)
0
40
80
40
60


Length 50% Maturity (cm)
0
40
50
60
1960
'65
'70
'75


42
40
38
36
34
32
30
28
Lenght at First Maturity
'70
'66
'67
'64
'71
'68
'65
'63
'62
'73
'72
'74
1.70
1.80
1.90
2.00
2.10
2.20
l_1 Growth Rate


Eggs = 11.260 N (ΔW)^1.222
Temp. 5 °C
Egg Catch Per Mature Fish (Egg / N)
300
200
100
0
0.1
0.2
0.3
0.4
0.5
0.6
Weighted Growth Rate of Mature Stock
'63
'67
'66
'75
'65
'70
'71
'69
'72
'73

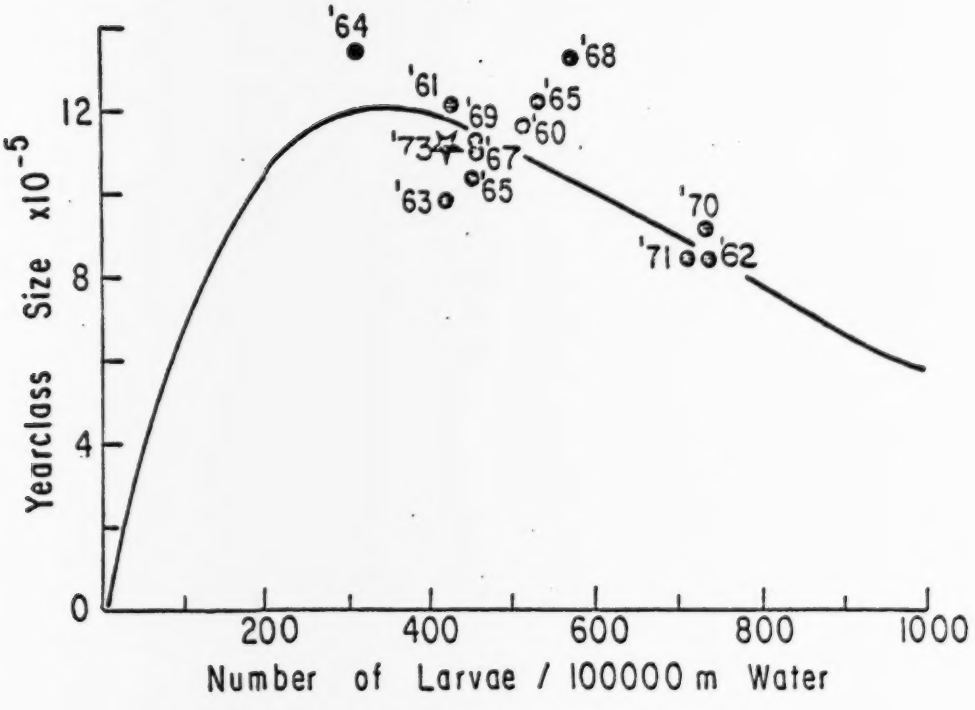
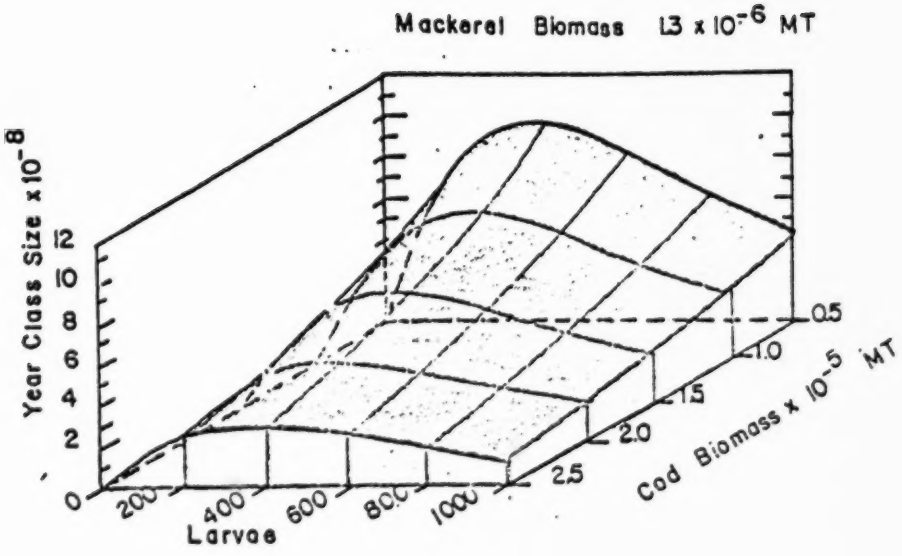

'64
'68
'61
'69
'65
'60
'73
'67
'63
'65
'70
'71
'62
12
8
4
0
Yearclass Size x10^{-5}
200
400
600
800
1000
Number of Larvae / 100000 m Water

Fig 3


Mackerel Biomass 1.3 x 10⁻⁶ MT
Year Class Size x10⁻⁸
0
2
4
6
8
10
12
200
400
600
800
1000
Larvae
0.5
1.0
1.5
2.0
2.5
Cod Biomass x 10⁻⁵ MT

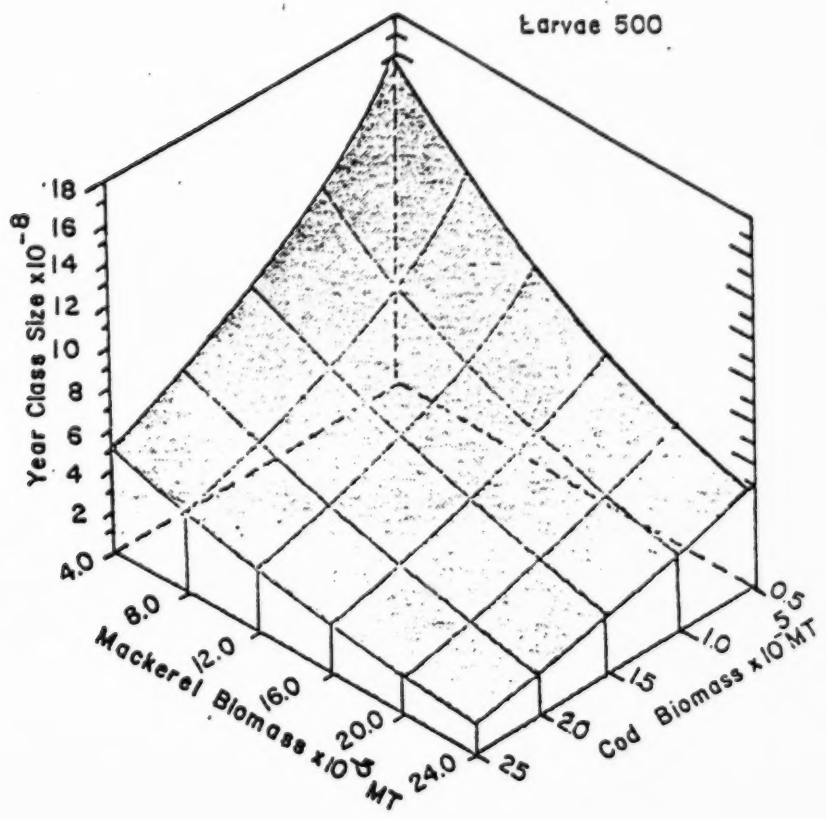
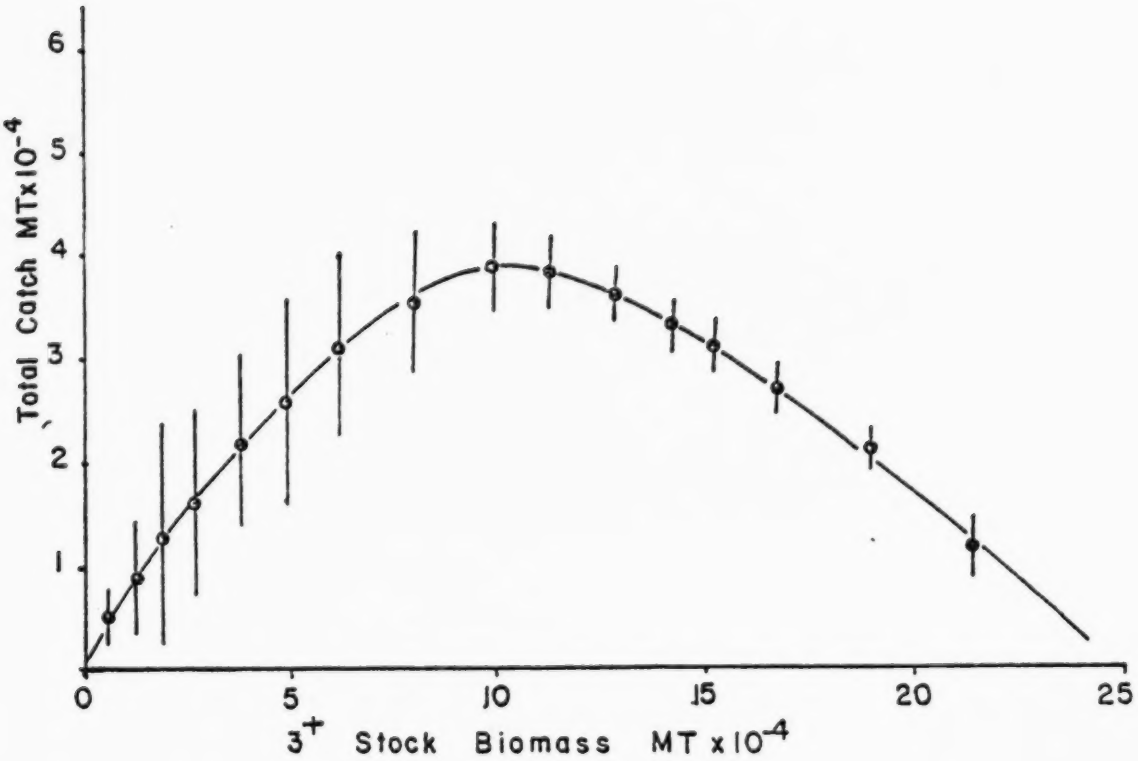

Larvae 500
Year Class Size x10⁻⁸
2
4
6
8
10
12
14
16
18
4.0
8.0
12.0
16.0
20.0
24.0
Mackerel Biomass x10⁻⁵ MT
0.5
1.0
1.5
2.0
2.5
Cod Biomass x10⁻⁵MT

Fig 14


Total Catch MTx10⁻⁴
6
5
4
3
2
1
0
5
10
15
20
25
3+ Stock Biomass MT x10⁻⁴

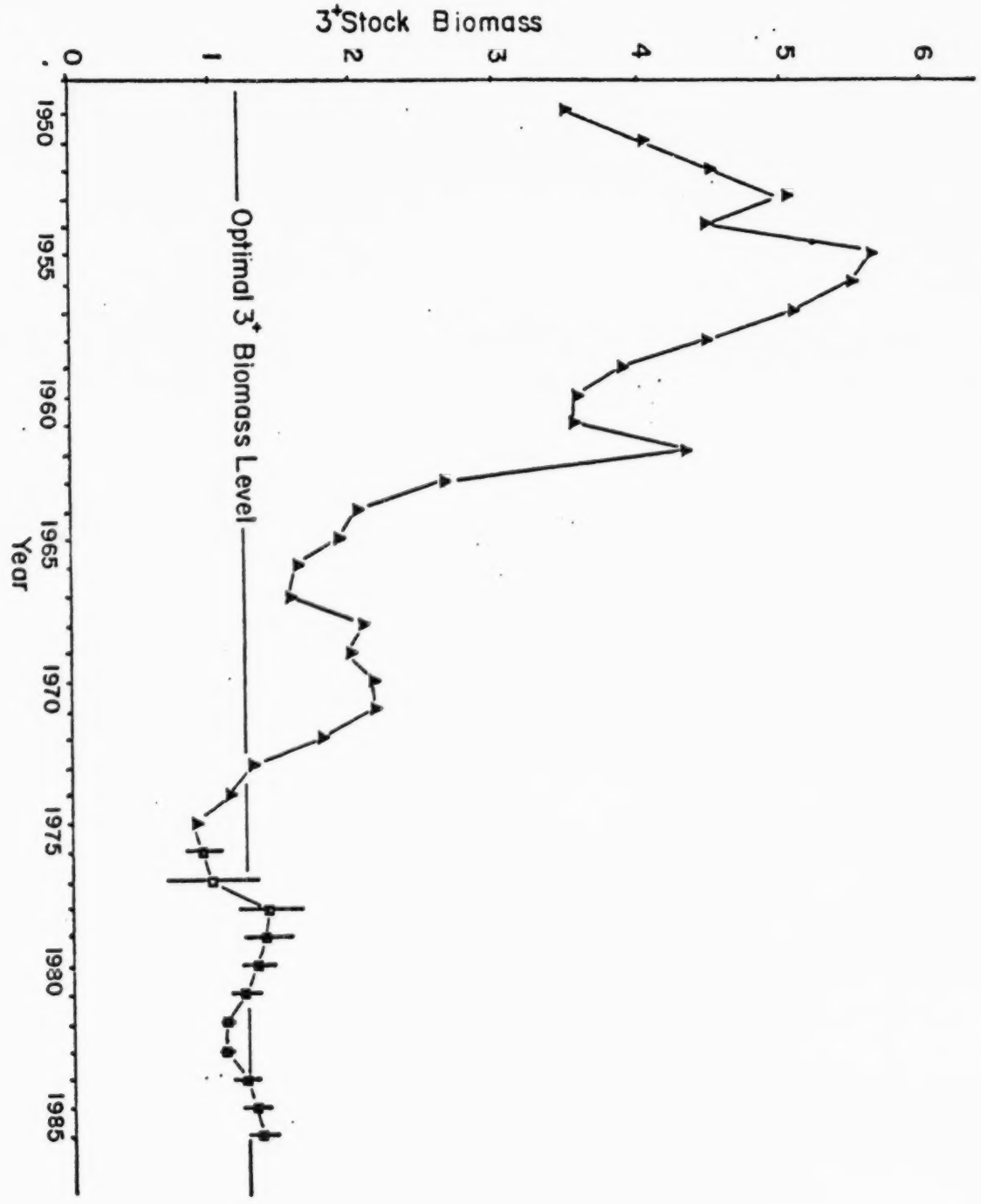

3+Stock Biomass
0
1
2
3
4
5
6
1950
1955
1960
1965
1970
1975
1980
1985
Year
Optimal 3+ Biomass Level

Table 1. Catch removed at age.

Age	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963
3	173	133	192	294	412	324	396	359	506	535	75	1	16	255
4	728	638	1034	2120	2968	2336	2612	2372	3341	3535	3967	3304	1720	2123
5	1559	1462	1915	5596	7832	6165	6727	6109	8607	9107	8983	13921	10897	4352
6	2703	2113	3104	5037	7049	5549	6648	6037	8506	9000	12515	9475	1889	16021
7	2772	2127	3065	4723	6596	5191	6331	5750	8101	8571	7144	8313	7870	14742
8	2495	1874	2643	3799	5319	4186	5223	4743	6683	7071	1736	2661	4290	6393
9	3327	2365	3141	3593	5029	3959	5381	4887	6895	7286	795	777	1490	3180
10	2193	1582	2146	2680	3751	2952	3878	3522	4961	5250	1812	506	589	984
11	901	638	843	942	1319	1038	1424	1293	1823	1929	388	741	153	392
12	478	351	483	636	890	701	902	819	1153	1221	279	385	178	137
13	138	106	153	235	329	259	316	287	405	428	76	198	37	102
14	128	94	130	173	243	191	245	222	314	332	93	174	26	37
15	79	58	80	106	148	117	150	136	192	203	51	33	36	50

Age	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
3	100	464	1498	700	310	327	26	2	1541	378	1229	2379	332
4	970	5504	7055	7069	8140	4936	3395	2476	14294	4396	3170	9902	4059
5	6728	6148	10689	5503	8066	12530	14972	7313	11326	11878	3862	6096	9089
6	5863	9292	4505	4586	4674	3571	11925	8941	7193	5982	9851	2350	4996
7	12038	4481	3423	3040	2916	2516	4194	6127	8479	4492	3631	3173	1513
8	9261	8524	1841	1735	1276	2136	1905	2567	5128	3455	2188	1250	834
9	3760	5534	2262	407	753	917	1444	1237	1370	2204	2081	1033	423
10	1133	1845	1890	1021	434	785	727	554	719	740	1186	738	220
11	347	1004	867	901	899	212	569	156	452	380	300	571	143
12	149	423	357	383	698	283	360	432	127	130	178	113	108
13	103	150	242	171	259	292	239	42	92	63	74	47	34
14	88	52	76	82	139	55	139	103	34	35	26	40	17
15	24	124	42	23	65	21	30	144	72	14	4	5	11

Table 4 . Selection at age for the weighted combination of the different gear types.

Age	1960	1961	1962	1963	1964	1965	1966	1967
3	0.619	0.000	0.022	0.236	0.330	0.748	0.572	0.301
4	0.753	0.678	0.385	0.343	0.562	0.696	0.664	0.722
5	0.891	0.722	0.593	0.615	0.696	0.750	0.846	0.857
6	0.956	0.859	0.764	0.801	0.776	0.810	0.899	0.871
7	0.989	0.964	0.909	0.894	0.894	0.906	0.962	0.938
8	0.989	1.000	0.992	0.969	0.972	0.943	0.982	0.952
9	0.956	0.992	1.000	1.000	1.000	0.995	1.000	0.931
10	0.975	0.872	0.807	0.939	0.929	1.000	0.988	0.977
11	0.754	0.776	0.386	0.810	0.740	0.934	0.908	1.000
12	0.299	0.457	0.817	0.603	0.775	0.769	0.766	0.993
13	0.247	0.271	0.527	0.887	0.337	0.535	0.544	0.817
14	0.113	0.167	0.287	0.611	0.551	0.789	0.441	0.885
15	0.598	0.324	0.092	0.934	0.287	0.734	0.394	0.531

Age	1968	1969	1970	1971	1972	1973	1974	1975
3	0.252	0.225	0.041	0.081	0.204	0.139	0.196	0.201
4	0.616	0.563	0.590	0.651	0.437	0.470	0.615	0.606
5	0.876	0.842	0.752	0.818	0.744	0.774	0.851	0.849
6	0.968	0.942	0.909	0.891	0.912	0.901	0.973	0.972
7	0.969	0.954	0.940	0.912	0.939	0.961	1.000	0.997
8	0.953	0.988	0.918	0.932	1.000	0.995	0.994	0.995
9	0.957	0.969	0.941	0.960	0.964	1.000	0.930	0.938
10	1.000	1.000	0.931	0.941	0.913	0.976	0.998	1.000
11	0.999	0.952	0.958	0.931	0.779	0.920	0.880	0.889
12	0.983	0.871	0.925	0.893	0.778	0.802	0.811	0.820
13	0.941	0.685	0.841	1.000	0.779	0.507	0.651	0.663
14	0.931	0.955	0.765	0.604	0.838	0.945	0.055	0.055
15	0.471	0.741	1.000	0.823	0.919	0.671	0.198	0.197

Table 3. Fishing mortality at age generated by cohort analysis for M = 0.2.

Age	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963
3	.002	.001	.002	.003	.006	.005	.005	.004	.005	.004	.001	.000	.000	.007
4	.011	.008	.013	.026	.038	.041	.052	.039	.043	.044	.038	.034	.052	.049
5	.028	.027	.028	.089	.124	.103	.160	.165	.194	.160	.152	.183	.148	.179
6	.074	.048	.072	.097	.155	.122	.154	.211	.365	.320	.343	.237	.034	.338
7	.116	.077	.091	.150	.178	.163	.199	.194	.485	.780	.456	.404	.317	.397
8	.169	.107	.130	.156	.252	.163	.246	.225	.363	1.095	.346	.305	.376	.462
9	.362	.240	.263	.262	.320	.302	.327	.384	.592	.872	.319	.256	.278	.518
10	.458	.292	.357	.377	.481	.315	.547	.370	.869	1.394	.550	.345	.315	.301
11	.329	.232	.250	.262	.322	.234	.246	.352	.332	1.072	.320	.455	.165	.358
12	.358	.205	.276	.303	.423	.283	.329	.218	.615	.389	.415	.610	.185	.219
13	.207	.124	.129	.210	.253	.207	.199	.163	.160	.486	.037	.550	.104	.154
14	.367	.212	.221	.211	.349	.228	.309	.209	.271	.190	.182	.111	.132	.144
15	.269	.260	.280	.280	.280	.280	.280	.280	.280	.280	.040	.090	.030	.400

Age	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
3	.002	.010	.027	.007	.004	.006	.001	.000	.075	.016	.035	.140	.015
4	.032	.130	.202	.174	.109	.073	.084	.069	.301	.318	.179	.433	.373
5	.215	.291	.398	.240	.308	.244	.329	.264	.505	.441	.515	.610	.910
6	.389	.520	.360	.296	.331	.217	.388	.334	.450	.551	.823	.694	1.700
7	.482	.597	.366	.442	.311	.298	.426	.354	.615	.569	.787	.693	1.463
8	.468	.708	.513	.320	.335	.394	.388	.506	.568	.549	.609	.700	.388
9	.548	.573	.406	.199	.223	.430	.509	.472	.561	.514	.773	.661	.536
10	.359	.575	.390	.323	.339	.383	.734	.373	.559	.685	.582	.704	.277
11	.164	.631	.591	.325	.528	.275	.534	.334	.599	.660	.688	.624	.275
12	.223	.308	.482	.571	.451	.311	1.071	1.061	.502	.340	.765	.575	.218
13	.254	.367	.291	.449	1.012	.344	.472	.319	.676	.503	.330	.462	.334
14	.193	.197	.321	.150	.829	.605	.273	.382	.465	.595	.399	.299	.299
15	.130	.450	.240	.150	.170	.270	.790	.500	.500	.350	.120	.122	.124

Table 4. Population numbers at age generated by cohort analysis for M = 0.2. Numbers in brackets are yearclass sizes predicted from juvenile surveys (see text).

Age	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963
3	113987	109640	113532	109046	78707	70001	82924	106681	110471	143344	134847	46119	60134	41739
4	76132	93169	89645	92779	88195	64067	57019	68353	87018	89988	116876	110335	37758	49219
5	62446	61673	75703	72460	74043	69522	50340	44320	53817	68221	70478	92101	87345	29357
6	41633	49716	49171	60247	54262	53534	51342	35128	30758	36274	47615	49574	62309	61662
7	27950	31841	38792	37449	44769	38048	38509	36020	23298	17486	21555	27660	32015	49715
8	17732	20376	23981	28987	26396	30685	26454	26046	24288	11745	6581	11184	15124	19090
9	12105	12260	14987	17243	20295	16799	21336	16933	17033	13838	3219	3801	6749	8501
10	6572	6901	7898	9428	10866	12066	10172	12599	9442	7716	4737	1915	2409	4185
11	3552	3405	4219	4524	5294	5502	7209	4819	7129	3241	1567	2239	1110	1449
12	1755	2093	2211	2691	2852	3141	3566	4613	2775	4187	908	932	1163	771
13	817	1004	1296	1373	1628	1530	1937	2103	3036	1229	2323	491	415	791
14	461	544	726	1005	912	1035	1018	1300	1463	2119	619	1833	232	306
15	356	261	360	477	666	527	675	612	864	913	1435	422	1344	167

Age	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
3	61261	52501	61455	107042	95111	56944	50480	74245	23460	26712	39388	20100 (50777)b	24538 (77027)
4	33942	50066	42565	48963	87005	77590	46326	41306	60785	17813	21528	31136	14304
5	28376	26912	36010	28465	33692	63868	59059	34856	31579	36833	10607	14757	16533
6	20093	25332	16471	19811	18326	20269	40954	34806	21921	15606	19409	5190	6567
7	35968	11150	12332	9409	12070	10775	13363	22740	20407	11439	7365	6977	2123
8	27264	16572	5074	7000	4953	7244	6545	7146	13074	9036	5301	2744	2841
9	9848	14024	7693	2489	4161	2900	3998	3635	3528	6064	4272	2360	1116
10	4148	4661	6475	4088	1669	2726	1545	1967	1857	1649	2971	1614	998
11	2537	2371	2147	3591	2423	974	1521	607	1109	870	681	1359	654
12	824	1763	1033	973	2125	1171	606	731	356	499	369	286	596
13	507	540	1061	523	450	1108	702	170	208	177	291	141	132
14	555	322	306	650	273	134	643	359	102	87	88	172	73
15	217	375	217	182	458	98	60	401	201	53	39	48	104

Table 5. Division 4T(Vn) cod. Landings in metric tons round by Canadian gear for 1976.

Gear Type	Length	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Traps (All Types)		-	0.5	4.4	-	0.2	0.8	3.9	3.6	0.1	0.2	-	-	13.7
Rakes & Tongs		-	-	-	-	-	0.1	-	-	-	-	-	-	0.1
Gill Nets (Drift)		-	-	-	-	1.3	5.9	0.6	12.5	-	-	5.0	-	25.3
" " (Set or Fixed)		-	-	-	10.4	240.3	904.0	1048.4	843.2	545.6	277.4	26.5	-	3891.8
Handlines		-	-	0.1	-	73.3	181.0	464.2	345.1	237.7	143.5	32.5	-	1478.3
Miscellaneous		-	-	0.1	-	0.9	19.1	188.6	195.4	112.2	62.1	5.9	-	584.3
Unspecified		-	-	-	-	0.1	62.9	145.6	21.7	4.1	1.2	4.3	-	239.9
Shrimp Trawlers	Under 70'	-	-	-	-	-	1.1	10.4	-	-	-	-	-	11.5
Side Otter Trawlers	Under 70'	12.4	-	-	9.2	843.6	1138.4	1162.6	916.0	752.1	303.3	59.7	33.1	5230.4
" " " "	70' Plus	1696.1	1184.6	216.3	359.5	646.2	121.1	15.1	0.7	15.8	75.4	360.8	669.4	5361.0
Stern Otter Trawlers	Under 70'	-	-	-	7.4	-	9.6	-	3.1	1.5	1.6	-	14.4	37.6
" " " "	70' Plus	7393.3	1343.8	2574.4	928.5	370.2	15.3	15.3	-	14.1	19.7	2.2	1683.5	14333.3
Longliners	Under 70'	-	-	0.3	9.4	82.1	35.7	91.2	108.2	124.1	116.4	80.2	28.1	657.7
" "	70' Plus	-	-	-	-	-	-	-	-	0.3	-	-	-	0.3
Midwater Trawlers	Under 70'	-	-	-	27.6	245.0	-	332.6	-	-	-	-	-	605.2
" " " "	70' Plus	110.3	-	573.8	35.4	90.6	-	-	-	17.2	-	160.8	197.9	1186.1
Danish Seiners		7.0	-	-	11.9	227.4	132.9	247.2	109.5	148.7	58.0	50.4	24.9	1017.9
Scottish Seiners		-	-	-	-	85.0	116.0	24.8	122.4	49.6	5.6	2.7	-	406.1
Pair Seiners		-	-	-	-	-	-	-	3.3	0.5	-	-	-	3.8
TOTAL														35102.3

Table 6 . Average fishing mortality values (F) for different age groups and weighted F values, stock numbers and biomass for different years.

Year	$\bar{F}$ 3 - 15	$\bar{F}$ 3 - 10	$\hat{F}$	3+ Stock Numbers	3+ Stock Biomass	4+ Stock Biomass
1950	.212	.191	.059	365491	354429	328896
1951	.143	.124	.041	392676	405232	380672
1952	.163	.148	.053	422614	456011	430580
1953	.187	.172	.082	436703	509540	485446
1954	.245	.230	.126	408879	449670	432118
1955	.188	.173	.108	366452	562851	546051
1956	.235	.226	.141	353794	554863	534637
1957	.216	.216	.126	359521	511663	488940
1958	.352	.386	.187	371385	446118	422920
1959	.545	.613	.207	400296	391884	362786
1960	.246	.294	.117	412732	356253	326992
1961	.275	.283	.145	348601	353630	344960
1962	.164	.187	.117	308600	434382	323136
1963	.271	.283	.240	266937	263724	254875
1964	.265	.286	.231	235659	202718	189976
1965	.411	.433	.292	208583	189350	177800
1966	.353	.373	.236	192636	173079	159128
1967	.281	.290	.138	233179	166965	146199
1968	.381	.294	.138	262711	206959	186796
1969	.296	.263	.144	245794	195758	180498
1970	.462	.446	.233	225797	213264	201502
1971	.382	.377	.175	222964	215405	197735
1972	.490	.473	.392	178580	176245	170356
1973	.468	.464	.375	126831	125271	117071
1974	.507	.574	.370	112301	113192	102518
1975	.517	.584	.455	86879	84589	76951

Table . Total 3+ biomass at different levels of fishing mortality in the summer and winter otter trawl fishery. Fishing mortality (F) in the line fishery is 0.06 while F in gillnet fishery is 0.09.

0	FWO	0.00	0.05	0.10	0.15	0.19	0.26	0.37	0.51	0.72	1.00	1.40	1.95
0	0.00	215929.	202469.	189684.	176448.	167778.	157358.	141979.	127087.	111903.	98476.	83273.	71239.
0	.05	202970.	190022.	178492.	168357.	160695.	148898.	133303.	120738.	106305.	94093.	81633.	70422.
0	.10	186710.	178920.	166624.	160212.	153938.	144428.	130877.	120676.	107653.	93411.	80113.	67634.
0	.15	178421.	170468.	162057.	155922.	149344.	138853.	129216.	117436.	105522.	91172.	78464.	68448.
0	.19	174124.	163752.	156040.	147340.	143420.	133097.	125766.	115352.	103433.	90393.	77539.	64385.
0	.26	161726.	154354.	148719.	141053.	137107.	129637.	119633.	110926.	97326.	87171.	75829.	64694.
0	.37	148255.	142235.	136681.	130643.	128140.	120985.	113270.	104433.	93929.	82535.	73499.	63553.
0	.51	132033.	128022.	122132.	118471.	115597.	111249.	104703.	98704.	87891.	80940.	69116.	59411.
0	.72	114908.	113413.	108522.	104192.	103409.	99538.	92680.	87594.	80132.	72581.	63633.	55339.
0	1.00	98887.	95384.	93293.	90885.	87283.	83544.	81014.	77042.	70959.	63214.	57833.	50541.
0	1.40	79179.	78945.	75442.	72670.	73802.	70559.	69071.	65192.	58736.	56133.	49233.	44600.
0	1.95	61439.	57710.	58965.	56061.	55830.	54632.	53457.	52326.	50286.	46406.	40494.	39512.

Table . Total catch at different levels of fishing mortality in the summer and winter otter trawl fishery.

0	FWO	0.00	0.05	0.10	0.15	0.19	0.26	0.37	0.51	0.72	1.00	1.40	1.95
0	0.00	10414.	15867.	20159.	23274.	25212.	28537.	31162.	33577.	34774.	35245.	33647.	31882.
0	.05	16816.	21012.	24254.	26796.	28244.	30510.	32848.	34604.	35630.	34686.	33688.	31992.
0	.10	21512.	25099.	27235.	29538.	30697.	32595.	34443.	35593.	36098.	35321.	33699.	31008.
0	.15	25706.	28477.	30447.	31658.	32789.	34090.	35471.	36330.	36669.	35374.	33522.	31822.
0	.19	28654.	30534.	32092.	33441.	33991.	35333.	36111.	36877.	36853.	35645.	33595.	30093.
0	.26	32568.	33940.	34875.	35734.	36293.	36940.	37112.	37500.	36227.	35508.	33395.	30707.
0	.37	36472.	37184.	37675.	37960.	38302.	38311.	38293.	37950.	36892.	34924.	33291.	30783.
0	.51	39279.	39652.	39188.	39349.	39373.	39436.	38960.	38609.	36680.	35826.	32605.	29442.
0	.72	40631.	41268.	40442.	39661.	39850.	39574.	37995.	37421.	35710.	33920.	31153.	28284.
0	1.00	40981.	40115.	39681.	39079.	38086.	37066.	36612.	35027.	33876.	31290.	29611.	26675.
0	1.40	37314.	37815.	36239.	34961.	35969.	34624.	34249.	32953.	30128.	29635.	26714.	24399.
0	1.95	32218.	30284.	30997.	29772.	29559.	29226.	28881.	28410.	27489.	25749.	22757.	22657.

Table 3 . Standard deviation of total catch.

0	FWO	0.00	0.05	0.10	0.15	0.19	0.26	0.37	0.51	0.72	1.00	1.40	1.95
0	0.00	482.	296.	138.	273.	311.	319.	599.	565.	1354.	1005.	3210.	1928.
0	.05	560.	379.	285.	438.	341.	434.	523.	669.	812.	1841.	2631.	1660.
0	.10	556.	810.	1041.	440.	555.	496.	564.	527.	903.	1134.	2101.	2929.
0	.15	718.	580.	435.	813.	592.	700.	704.	744.	785.	1765.	2798.	2313.
0	.19	308.	477.	628.	611.	394.	360.	562.	560.	470.	1403.	1885.	4342.
0	.26	396.	585.	351.	385.	492.	580.	884.	607.	1743.	2360.	2706.	2769.
0	.37	553.	386.	556.	856.	432.	796.	1045.	1096.	1696.	2384.	2639.	2407.
0	.51	1015.	584.	1131.	1336.	975.	703.	1336.	1608.	1847.	1389.	2435.	2784.
0	.72	1550.	605.	1564.	2325.	1903.	1479.	2466.	2354.	2545.	2924.	2489.	4140.
0	1.00	1460.	2123.	2091.	2620.	2585.	2512.	3348.	2983.	4033.	3535.	3502.	3433.
0	1.40	2478.	2349.	2922.	3196.	1940.	3407.	3005.	3606.	3784.	4292.	3958.	3708.
0	1.95	2954.	3407.	3016.	5472.	2695.	3183.	3657.	3804.	3675.	4371.	4834.	2848.

Table 12. Weighted fishing mortalities resulting from varying fishing mortalities in the summer and winter otter trawl fishery. Fishing mortality in the line fishery is 0.06 and 0.09 in the gillnet fishery. The top value is the weight F for summer and the bottom is the winter OT weighted F.

0 FUD	0.00	0.05	0.10	0.15	0.19	0.26	0.37	0.51	0.72	1.00	1.40	1.95
0 0.00	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	.0207	.0382	.0538	.0640	.0810	.1025	.1250	.1539	.1863	.2240	.2699
0 .05	.0266	.0246	.0230	.0219	.0211	.0196	.0170	.0161	.0145	.0128	.0113	.0100
	0.000	.0189	.0349	.0492	.0595	.0757	.0951	.1187	.1464	.1774	.2150	.2632
0 .10	.0498	.0470	.0442	.0419	.0401	.0374	.0345	.0317	.0284	.0251	.0226	.0198
	0.0000	.0175	.0323	.0456	.0547	.0703	.0894	.1130	.1394	.1699	.2109	.2548
0 .15	.0704	.0664	.0627	.0602	.0577	.0540	.0501	.0459	.0419	.0375	.0334	.0297
	0.0000	.0158	.0296	.0422	.0506	.0666	.0842	.1063	.1336	.1646	.2031	.2497
0 .19	.0835	.0801	.0761	.0727	.0699	.0661	.0615	.0569	.0518	.0464	.0416	.0368
	0.0000	.0148	.0278	.0395	.0476	.0623	.0801	.1023	.1286	.1585	.1970	.2409
0 .26	.1089	.1042	.0992	.0962	.0932	.0884	.0833	.0771	.0700	.0636	.0568	.0511
	0.0000	.0131	.0247	.0358	.0435	.0570	.0745	.0953	.1196	.1504	.1869	.2315
0 .37	.1393	.1333	.1294	.1246	.1215	.1164	.1093	.1033	.0941	.0868	.0776	.0703
	0.0000	.0112	.0217	.0311	.0392	.0507	.0661	.0865	.1093	.1401	.1735	.2200
0 .51	.1740	.1691	.1653	.1581	.1556	.1502	.1441	.1352	.1263	.1171	.1073	.0958
	0.0000	.0094	.0182	.0260	.0322	.0432	.0578	.0752	.0978	.1263	.1609	.2008
0 .72	.2190	.2146	.2083	.2036	.1988	.1953	.1860	.1769	.1676	.1583	.1459	.1347
	0.0000	.0076	.0147	.0215	.0264	.0362	.0480	.0637	.0845	.1113	.1423	.1850
0 1.00	.2722	.2673	.2624	.2596	.2568	.2489	.2402	.2319	.2193	.2082	.1954	.1799
	0.0000	.0059	.0115	.0172	.0212	.0298	.0391	.0527	.0696	.0929	.1232	.1591
0 1.40	.3406	.3347	.3364	.3238	.3287	.3210	.3129	.3043	.2919	.2802	.2632	.2425
	0.0000	.0044	.0089	.0129	.0165	.0225	.0309	.0420	.0568	.0765	.1009	.1330
0 1.95	.4363	.4272	.4196	.4261	.4144	.4159	.4078	.3974	.3842	.3729	.3578	.3399
	0.0000	.0033	.0065	.0100	.0123	.0172	.0235	.0324	.0443	.0598	.0822	.1112